Environmental Sustainability Dynamics of an Industrial System: A case study on the UK Medical Technology sector

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Abstract

This paper investigates environmental sustainability dynamics of an industrial system through a case study on the UK Medical Technology sector. This paper builds on industrial system framework involving institutions, specialist firms, value/supply chains and industrial actors. Environmental sustainability dynamics are explored through infrastructure and structure factors of industrial systems that are primarily developed from theoretical domains of manufacturing systems, production networks and supply chains. Research findings suggest that structural components influence the industry system more radically than the infrastructural components. Environmental sustainability dynamics depend on size of industrial actors, types/characteristics of product and process, and availability of specialist (funding/technology) firms.

Keywords: 1) Sustainability in Operations and Logistics, (2) Healthcare Operations Management, (3) Supply Network Design

Introduction

Environmental sustainability has been described as one of the greatest challenges over the coming decades. In 2008, the UK government passed the ‘Climate Change Act’, requiring an 80% national reduction in greenhouse gas emissions by 2050 based on a 1990 baseline, supported by reductions of 34% by 2020 and 50% by 2025. It is suggested that 30% or more of the GHG generated is due to the inefficiencies of industrial systems in developed countries (Evans, Bergendahl, Gregory, & Ryan, 2009). This implies that there is a need to approach sustainability from a systems view in order to understand the environmental sustainability dynamics (Seuring & Gold, 2013). These dynamics can be explained by understanding what influences a complex industrial system for environmental sustainability and how (Forrester, 1958). Therefore this paper addresses the research question – How does an industrial system become influenced for the development of environmental sustainable operations?

Theoretical foundation

Industrial system

Manufacturing systems have evolved from simple raw material transformation in a factory to a highly complicated industrial system that *"Include(s) the context, resources, activities, processes, actors, and interdependencies that support the creation and delivery of products and services"(Kumar & Gregory, 2013; RAC, 2012)*. Today, the actors involved in manufacturing not only include the global industrial actors, but other external stakeholders. Theoretical work on clusters, business ecosystems and industry structure have highlighted the importance of institutions (e.g. through research, policy/regulation, knowledge transfer) and specialists (e.g. through funding, specialist equipment, technical support and services) that support an industry (Kumar, Srai, Pattinson, & Gregory, 2013; Luo, Whitney, Baldwin, & Magee, 2011; Porter, 1998; Srai, 2010; Srai, Christodoulou, & Harrington, 2014). This research draws on industrial system frameworks with multiple subsystems/levels including institutions and specialists, Industrial Value/supply Chain (VC/SC), core process/products and industrial actors (Figure 1).

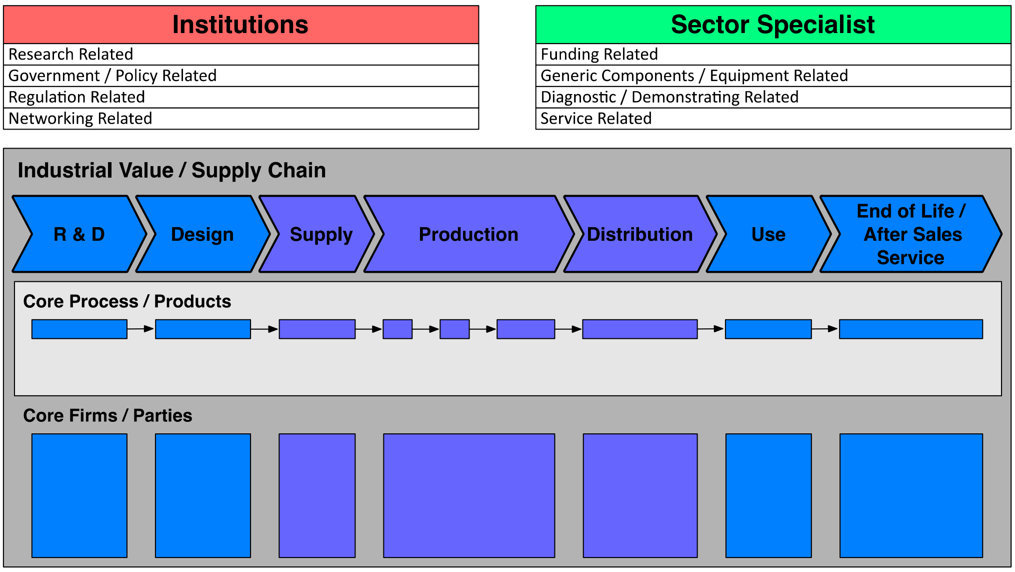

Figure 1: Industrial System Framework developed from (Kumar et al., 2013; Srai, 2010; Srai et al., 2014)

Dynamics or influences in Industrial systems

Skinner was one of the earliest pioneers to expand the view towards manufacturing, involving a pattern of individual decision and their influences to meet long term company objectives (Skinner, 1969). This view was expanded by Hayes and Wheelwright to observe manufacturing from a factory system perspective by considering the structural (capacity, facilities, technology, vertical integration) and infrastructural (workforce, quality, planning/control, organisational structure) elements (Hayes & Wheelwright, 1984). Generally, these two types of elements are interdependent but have different characteristics. Theoretically, changes in any or all of the structural and infrastructural elements reconfigure or transform a system. The structure has a more radical and architectural influence on the system, whereas the infrastructure determines daily operations as well as accumulative improvements (Shi & Gregory, 1998). Therefore, if we can develop infrastructural and structural elements of an industrial system then we can observe dynamics, specifically, in this research, for environmental dynamics. During the late 1990's, further emphasis on the geographical location and coordination of factories was placed by Shi & Gregory, leading to the international manufacturing perspective (Shi & Gregory, 1998). In 1999, the importance of globalisation in co-operative and inter-organisational supplier relations was highlighted, leading to the theory of supply chain as a system (Harland, Lamming, & Cousins, 1999). Building on the evolving nature of structure and infrastructure components discussed by authors such as Hayes & Wheelwright and Shi & Gregory, a new set of constructs for an industrial system is proposed, shown in table 2. It is important to note that companies traditionally take decisions influencing the structure and infrastructure of manufacturing systems. Whereas in an industrial system, a mixture of external stakeholders and industrial actors make these decisions.

Table 1: Evolution of structural and infrastructural construct of a system

System Types	Structure (Architecture)	Infrastructure (Mechanism)
Factory (Hayes & Wheelwright, 1984)	• Capacity • Facilities • Technology • Vertical integration	• Workforce • Quality • Planning / control • Organisational structure
International Manufacturing (Shi & Gregory, 1998)	• Factory's characteristics (above) • Geographic dispersion • Horizontal coordination • Vertical coordination	• Dynamic response mechanism • Learning / knowledge transfer • Operational mechanism • Organisational / network evolution
Supply Chain (Harland et al., 1999)	• Capacity • Role configuration • Facility configuration • Make or buy	• SC HR policy • Supplier Quality • Planning / control • Organisation structure • New product development • Performance measurement
Industrial System (Porter, 1998; Sturgeon, 2001; Moore, 2005; Jacobides et al., 2006; Porter, 2007; Brusoni et al., 2009; Evans et al., 2009; Whitney et al., 2011; The Royal Academy of Engineering, 2012; Srai & Christodoulou, 2014)	• Product/service characteristics • VC/SC processes • Capacity (including R&D, Production, import/export etc.) • Roles and relationship between institutions, specialists, VC/SC and industrial actors • Technology	• Industrial Actors • Product/Service Quality • New product/process development • Institutions/Specialist involvement (e.g. policy, regulation, knowledge transfer)

Environment sustainability

There is a need to approach sustainability from a systems view in order to understand the dynamics and implications of different environmental activities (Evans et al., 2009; Seuring & Gold, 2013). Various authors have proposed that in order to achieve industrial sustainability, activities targeted at multiple levels or sub-systems are necessary (Braungart, McDonough, & Bollinger, 2007; Chertow, 2000; Fiksel, 2003; Marchi, Maria, & Micelli, 2013). Following this view, fragmented literature on environmental activities were reviewed and categorised into three levels defined in the industrial system - Institution/Specialist, VC/SC, and Industrial Actor (Figure 1). These activities range from Industrial symbiosis and circular economy at the institutional level to waste minimisation and pollution control at the industrial actors level involving production. This categorisation suggests that these activities have different perspectives. The VC/SC level has a higher focus on the activities requiring collaboration with multiple actors, whereas industrial actor level is primarily an in-house activity. For example, green/eco design can be achieved through both collaboration or individually.

Table 2: Environmental suitability activities

Institution/Specialist Level		**Industrial Actor Level**	
Environmental Sustainability Concepts	Source No.	**Eco Design**	Source No.
• Industrial ecology	1,2,6,10,27	• Design for material and product recovery	5,13,14
- industrial ecosystem	1,6,10,12	• Design for disassembly	14,15,18
- industrial symbiosis / Eco-industrial park	1,26,27,28	• Design for waste minimization	1,19
- Circular economy	38,39	• Design for remanufacturing	1,5,14
- Cradle to cradle	1,11,12	• Design for recycling issues	1,5,14
• Zero waste / zero emission	1, 12,40	• Design for dematerialisation	1,21
Environmental Policy/Strategy	Source No.	• Design for reuse / modularity	17,20
• Environmental policy	49, 59, 51,52	• Design for product life extension	19,29
- Sustainable production / green operation	1,6	• Design under legislation and regulations	16,19
- Sustainable consumption	1,46,53	• Packaging design	17,22
• Industrial pollution prevention strategy	2,6	• Better choices of material	23,24,35
• Product service system strategy	*see right*	• Green chemistry	1,2,6
• Life cycle assessment	*see right*	**Product Recovery**	Source No.
• Renewable energy sourcing	*see right*	• Recycling	1,6,29
Environmental Legalisation/Schemes	Source No.	- upcycling	25,26
• Environmental regulation	16,19,47,50	- downcycling	12,27
• Environmental standards	8,41	• Reuse	1,6,29
- ISO 14001	1,2,8,41,45,48	• Repair	1,6,29
- Eco-management and auditing scheme (EMAS)	1,42,43,45	• Regeneration	1,28
- Responsible care	1,45	• Refurbish	6,7
• Voluntary environmental agreements	1,42	• Remanufacturing	1,5,6,29
Value/Supply Chain Level		• Dis-assembly	6,29
Green Value/Supply Chain Management	Source No.	**Green Production**	Source No.
• Green design	*see right*	• Cleaner production	1, 5,10,31
• Green procurement	9,37	• End of pipe practise	1,31,32
• Green manufacturing (inc. product recovery)	*see right*	• Pollution control	1,32
• Green logistics	6,9,16,17	• Pollution prevention	1,32
• Green network	6,9,12,16	• Waste minimization	1,6
• Green waste management	6,17	• Quality / lean / TQM / JIT techniques	5,8
• Green strategy	1,2,4,5,6,9	• Use of by-products (e.g. waste heat)	5,8
• Product life extension	5,17	**Green Corporate Policy / Strategy**	Source No.
• Life cycle assessment	*see right*	• Eco-efficiency	1,4,10,11,12
Environmental Collaboration	Source No.	• Eco-effectiveness	10,11,12
• Extended producer responsibility	12,19	• Environmentally neutral / responsive strategy	30
• Intelligent material pooling	12	• Beyond compliance / environmental leadership strategy	4,8,30,33
• Shared risk and benefits / knowledge sharing	9,33	• Eco branding strategy	4,33
		• Environmental cost leadership strategy	4,33
		• Selection of pollution prevention strategies	1,2,6,9
		• Product service system strategy	1,5,17,54
		• Implementation of environmental management system / regulatory compliance	1,2,8,9,17
		• Renewable energy sourcing	34,36
		• Environmental accounting	1,17
		- Life cycle assessment	1,2,3,5
		- ERW framework	55, 56
		• Application of quality / lean / TQM / JIT principle	5,8,9

Approach

Due to the focus on the emerging phenomena of understanding environmental dynamics within an industrial system, a case study methodology is selected. As the focus of this research is on environmental sustainability dynamics within an industrial system, various complex relations are investigated between external stakeholders, processes and industrial actors. Based on a set criterion, a UK Medical Technology Sector (UKMTS) case study is selected covering two product categories- (a) In Vitro Diagnostic (IVD), and (b) Single Use Instrument (SUI) with four products – PCR system, SMBG system, Single use Syringe and Single use Forceps. The case study approach involved mapping the industrial system from secondary data and then validating these maps with primary data. Four product based industrial systems are mapped. The primary data are collected based on interviews. The format of the interview was semi-structured rather than structured due to the nature of this study requiring interviews from various actors. Key stakeholders to interview were chosen from the institutions, specialists and industrial actors identified from the initial industrial system map development process. On average, 45 min interviews were conducted with a total of 19 interviewees. The positions of the interviewees ranged from high level (e.g. managing director, head of department) to general managers (e.g. R&D, quality, regulatory). Data analysis was structured around key concepts derived from the literature. With-in-case analysis and cross case analysis was performed to identify key evidence of environmental sustainability influences and within an industrial system, along with pattern matching for environmental sustainability influences which helped to link the data with the key findings (Figure 2, 3, 4 and 5).

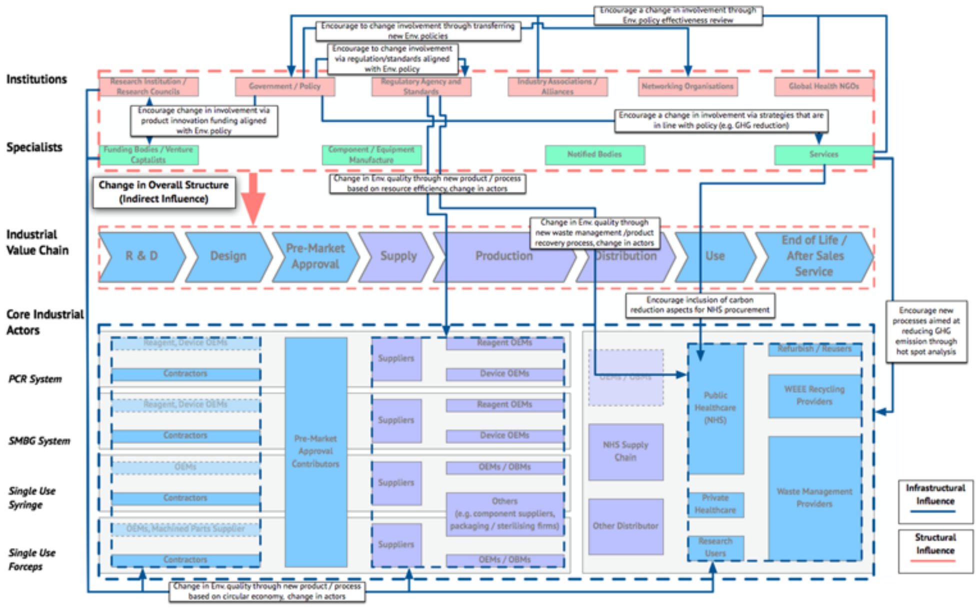

Figure 2: Influence of environmental sustainability at the institution and specialist levels

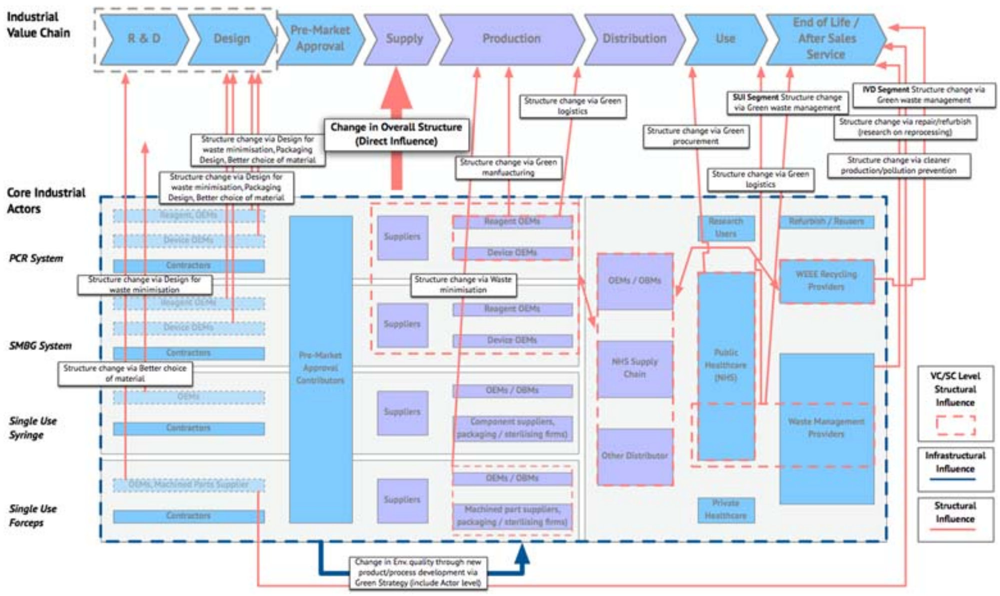

Figure 3: Influence of environmental sustainability at the VC/SC and Industrial actor levels

		In Vitro Diagnostic Segment		Single Use Segment	
		PCR System	SMBG System	Single Use Syringe	Single Use Forceps
Structure	**Product Characteristics**				
	Technology	biotechnology, electrical, mechanical		mechanical	
	No. components	very high	high	low	few
	Components/materials used	mix of plastic, metal, electronic components, LCD screen, internal computer, sensors, (bio)chemicals etc.		mix of plastic, rubber, metal etc.	metal (e.g. stainless steel)
	Value	high	medium	low	
	Purpose	diagnostic/research	diagnostic	clinical	
	VC/SC Processes				
	R&D, Design	complicated (esp. diagnostic reagent)		moderate	simple
	Pre-Market Approval	CE approval route depends on its use (research or diagnostic)	device and test strip follows the IVDD route, whereas a lancet follows the MDD for CE approval	both follows the MDD route for CE approval	
	Supply Chain Development	complex due to various components/materials required for both instrument and reagent		relatively simple since several components/materials required	simple due to only metal is required
	Production	variety of production stages involved (machining, assembly, chemical processing etc.)		main production stages include needle and plastic moulding	various different machining stages (mainly outsourced)
	Distribution	Mainly through direct to market from OEMs/OBMs, NHS Supply Chain or other distributors			
	Market	public/private healthcare, university/labs, biotech/pharma companies etc.	mainly public/private healthcare and pharmacies	mainly public/private healthcare	
	End of Life / After Sales Service	refurbish/remanufacturing/reuse, recycling, incinerate/landfill	recycling, incinerate/landfill	primary incinerate/landfill	mix of recycling and incinerate/landfill
	Capacity				
	R&D, Design	relatively high capacity from high interest from industrial actors as well as external stakeholders		relatively low	low
	Pre-Market Approval	higher capacity due to emerging sector		relatively low capacity due to established field	
	Supply Chain Development	• low capacity for reagents (mainly from Europe) • moderate capacity for research use instrument (sourced locally)	n/a	n/a	low capacity (mainly from East Asia and Europe)
	Production	higher production capacity on reagents		more Globally than UK	low machining capacity (due to majority outsourced)
	Distribution	highest capacity through direct to market		mix	highest capacity through direct to market
	Market	higher reagent capacity than instrument (esp. research use in the case of PCR)		higher capacity for public healthcare	
	End of Life / After Sales Service	highest capacity on recycling		most products follow incineration/landfill	higher capacity on incineration/landfill
	Product Imports/Exports	higher import capacity than exports (some reagent exports)	almost exclusively imports for UK market (some reagent exports)	higher import capacity than exports	relatively high exports
	Roles and Relationship				
	Institutions	various interactions within different institutions as well as with industrial actors			
	Specialists	various interactions with a specific part of the value chain as well as with industrial actors (e.g. direction of research funding)			
	Industrial Actors	main interactions with suppliers/customers as well as with external stakeholders (e.g. research partnerships, regulation, lobbying)			
	Technology				
	Production	mainly manual methods (e.g. mixing, machining) involved	mix of manual (for device) and automated (for test strip)	automated technology can used	mainly manual machining
	Communication	mix of IT and manual data communication			
Infrastructure	**Industrial Actor**				
	R&D, Design	mix of MNCs, SMEs and ODMs			mix of UK OEMs and machined parts suppliers
	Pre-Market Approval	generally more parties involved (e.g. NICE, MHRA) due to the innovative nature of the devices		generally simple mechanism due to relatively simple technology involvement/long existence of devices	
	Supply Chain Development	low UK based supplier from most production occurring globally		n/a	suppliers concentrating in East Asia and Europe
	Production	• high ratio of geographical presence of MNCs although only one company with production facility in the UK was observed • moderate ratio of UK OEMs for reagent production	• high ratio of geographical presence of MNCs although only one company with production facility in the UK was observed • very few UK OEM presence	• high ratio of geographical presence of MNCs in general • moderate ratio of UK OEM presence • some other UK based firms (e.g. for needle production)	• high ratio of Pakistan based machined parts supplier as well as UK OEM/OBM presence • some other UK based firms (e.g. for outsourced packaging)
	Distribution	Similar actor types (OEMs, OBMs for direct to market, NHS Supply Chain and other distributors)			
	Market	Various users involved due to the multiple device use nature (diagnostic or research)	Multiple user types involved from the device used by healthcare professionals and consumers	Relatively few user types involvement due to devices used predominantly by healthcare professionals	
	End of Life / After Sales Service	Various actors involved due to many end of life options	Multiple actors involved from more than one end of life	Generally only one end of life player type	Multiple actors involved from more than one end of life
	External Stakeholder Involvement				
	Institutions	• high involvement of product related research (mainly biotechnology rather than mechanical/electrical) • high involvement of global health NGOs due to epidemic nature of immunology / diabetes • focus of regulation is due to the risk of devices from the interpretation of test results		• research focus on health & safety aspects (e.g. decontamination) • high involvement of regulators and trade unions regarding health & safety of product users • focus of regulation is due to the risk of devices from the potential physical harm to the patients/users	
		legislation difference between diagnostic and research use devices (IVDD vs. EMCD & LVD)	further focus on accuracy of data and reliability due to self testing nature of product (ISO 15197)	further focus on blood-born disease: *The Sharps Regulation (Sharps Instruments in Healthcare) Regulations 2013*	further focus on reprocessing instruments
	Specialists	more commercial fundings are available and more component/equipment manufactures as well as notified bodies are		*relatively lower involvement compared to IVD sector*	
		relatively complex overall notified body involvement due to difference in device use	relatively complex overall notified body involvement due to difference in component purpose	relatively complex notified body involvement from various ISO standards that may be applicable	relatively simple notified body structure
	Product / Service Quality				
	Quality	high quality is maintained through strict regulations and quality management standards (e.g. ISO 9001 / 13485) due to concern on health & safety of patients			
	New Product/Process Development				
	New Products	focus on higher efficiency, new platform, new assay tests	focus on next-generation sensing technology, safety and comfort	focus on safety/shielding mechanism, new drug delivery methods (e.g. needle-free)	focus on new material and customer design requirements
	New Process	new process to prepare for the new IVD Directive (on-going review since 2012)	new process to prepare for the new IVD, MD Directive (on-going review since 2012)	new process to prepare for the new MD Directive (on-going review since 2012)	

Applicable to IVD Segment (PCR System, SMBG System) and SUI Segment (Syringe, Forceps)
Applicable to IVD or SUI Segment
Applicable to Specific Product

Figure 4: Structure and Infrastructure of UKMTS Industrial system (With-in-Case Analysis)

		In Vitro Diagnostic Segment		Single Use Segment	
		PCR System	SMBG System	Single Use Syringe	Single Use Forceps
Key Environmental Challenges / Activities	**Institution/Specialist Level**				
	Policy	• focus on green economy: encourage resource efficiency and environmental management, promotion of eco-innovation, improving the sustainable consumption, focus on waste/product recovery, and to achieve 80% GHG reduction by 2050			
	Strategy	• developing medical technology industrial strategy for Climate Change National Adaptation Plan as well as more specific strategies regarding each product from the highlights on specific carbon hotspots (by SDU)			
	Regulation	• setting regulations in line with above policy as well as ensuring a balance between health & safety aspects • to improve product recovery (e.g. setting landfill tax (£80 per tonne) to divert waste from landfill and regulating exports to avoid leakage of valuable material)			
	Funding	• funding research on all TRL that support circular economy principle			
	Knowledge Transfer	• to provide strategy, guidance and tools to industrial actors as well as external stakeholders to support environmental policies			
	Lobbying	• consultation to align UK environmental sustainability policy direction with EU level • consultation regarding landfill taxation policy to incentivise products that are designed to have lower environmental impact and support greater reuse/repair • possible inclusion of environmental aspects in the HTA from NICE			
	Value/Supply Chain Level				
	Green Manufacturing	waste minimisation (MNC)			GHG reduction through onshoring manufacturing (SME)
	Green Procurement	more sustainable consumption through inclusion of carbon reduction aspects for NHS procurement (UK user)			
		sustainable consumption through inclusion of IVD EEE for EU Green Public Procurement Guideline (UK user)			
	Green Logistics	reduction of carbon footprint through achieving carbon fleet neutral through carbon offsetting company or balancing 'just in time' deliver with no. of delivery per day (end of life firm)			
		reduce waste and carbon foot print via reduction of refrigerant for reagent transport (MNC)			
	Green Waste Management			• reducing waste through reusable sharps bin and collaboration with UK users(end of life firm) • increase in product recovery via recycling contents of single use syringes with collaboration with end of life firms (MNC)	• increase in product recovery through collaboration with UK users to segregate and recycle stainless steel via scrap metal (end of life firm) • increase in product recovery through recycling of metals through economic incentive (SME)
				reducing waste through reprocessing (end of life firm)	
	Green Strategy	• reduction of carbon footprint through investigating carbon 'hot spots' for a particular product (UK manufacture) • increased product recovery from further bringing back sterilisation to the hospitals (e.g. Hospital Sterilisation and Disinfection Unit, HSDU) • improved resource efficiency and waste through E-procurement strategies leading to lower via paperless system (e.g. UDI GS1 compliant barcodes)			
	Extended Producer Responsibility	increase in product recovery/resource efficiency through compliance to WEEE, RoHS directive (IVD actors)			
	Shared Risk and Benefits / Knowledge Sharing	overall improvement through collaboration with other industrial actors (e.g. OEMs, NHS, waste management firms) (Industrial actors)			
	Industrial Actor Level				
	Eco Design				
	• Design for waste minimisation	• reducing waste from reducing power usage of instruments (SME) • research and production of freeze dried reagents that can significantly reduce carbon fleet (SME)	• reducing waste from designing a SMBG system using significantly less consumables (MNC) • reducing waste through smaller, lighter packaging (MNC)	• reducing waste/carbon emission through designing syringes with much lower plastic content (MNC)	
	• Packaging Design	• research and implementation of biodegradable packaging to eliminate waste (MNC)			
	• Better choice of material	• research and implementation of sustainable material (bio-plastic) for reagent packaging (SME)	• increasing product recovery through the use of sustainable material for packaging materials (MNC)		• reduction in carbon footprint through research to substitute stainless steel into polymer to justify onshoring via automation (SME)
	Product Recovery				
	• Reuse				• Future research on reprocessing in order to assess its contamination issue
	Green Production				
	• Cleaner Production / Pollution Prevention	• increase in environmental management through using less polluting hydroclave as an alternative to incineration (end of life firm) • recovering energy from incinerating healthcare waste (end of life firm)			
	Green Corporate Policy / Strategy				
	• Eco-efficiency	• process/product improvements to reduce waste (MNC)	• Green building design and construction initiatives (e.g. LEED) (MNC) • Eco-innovation through Product Stewardship strategy (MNC)		
	• Beyond compliance / Environmental Leadership	increase resource efficiency and product recovery through applying industrial ecology model to product development/production (MNC)			
			• rigorous volunteering of carbon emission reduction (MNC)		
	• Renewable energy sourcing		• incorporate renewable energy sourcing methods (MNC)		
	• Selection of pollution prevention strategy	• online diagnostic procedures to save replacement carbon fleet (SME)			
	• Implementation of EMS / Regulatory compliance	implementing EMS (e.g. ISO 14001) to a number of actors, especially SMEs and others wishing to become a waste management provider (can be through green funding opportunities)			
		• implementation of EMS through the use of green funding (SME) • compliance to revised regulation with anticipated increase in toxicity of future reagents (SME)			
	• Environmental accounting (LCA)			• performing LCA to investigate the trade-off between benefits gained from recycling, additional transportation and refurbishment of materials, etc. (MNC)	• LCA activities to compare carbon footprint of outsourcing manufacturing to. UK manufactured goods (SME)

Applicable to IVD Segment (PCR System, SMBG System) and SUI Segment (Syringe, Forceps)
Applicable to IVD or SUI Segment
Applicable to Specific Product

Figure 5: Environmental sustainability focus and challenges (Cross-case analysis)

Discussion

Environmental sustainability dynamics at the Institution/Specialist Level: Governmental policies are encouraging basic/applied research councils as well as commercial research funding to change their involvement through product innovation and funding projects that are aligned with the environmental policies. Regarding commercial funding, it was stated by the Head of Sustainability of the Technology Strategy Board - *"The goal is to build sustainability and resource efficiency in the UK economy through mainly funding projects that are relative to the circular economy and assist in transforming the industrial system"*. These research/funding activities aim to influence industrial actors in an infrastructural way through encouraging a change in product/service quality, new products/processes based on the circular economy, change of actors etc. Environmental policies are influencing regulators to change their involvement with industrial actors through setting revised regulations and standards. Another example of an infrastructural influence of environmental policies and legislation can be seen from the Sustainable Development Unit (SDU). SDU is a specialist service provider that develops tools, strategies and research that will enable UKMTS actors to promote sustainable development. The SDU's Head of Unit stated, *"Due to the UK being the only European country which has a legislation on the carbon footprint reduction from the Climate Change Act, it was a good entry point for SDU to first tackle this, whereas other EU countries may be looking at toxicity first"*. There are various other infrastructural influences regarding environmental sustainability at the institution/specialist level that are captured in figure 2. It can be concluded that the majority of the environmental sustainability activities in the institutional/specialist level are aimed to influence the structure of the UKMTS System indirectly.

Environmental sustainability dynamics at VC/SC and Industrial Actor Levels: It was observed that infrastructural influences from the institutions/specialists could be translated into green strategies, which will encourage new processes/products to be developed internally. An example is the E-procurement strategy revised to be placed between different actors along the supply chain in order to influence the infrastructure by encouraging a more resource efficient procurement process, stated by a Senior Quality Manager, Forceps Manufacture. Comparing SMEs and MNCs, a different approach to environmental sustainability was observed. A Sustainable Policy Assistant from a Medical Technology MNC has stated, *"Amongst medical technology companies, all comply with environmental legislation, with some looking at it as an opportunity such as Johnson & Johnson (J&J), Baxter and BD"*. In contrast, it was stated by a Policy Advisor in the Association of British Healthcare Industry (ABHI), *"With most UK based medical device companies being SMEs, there is not a high focus on environmental sustainability compared to other industries such as Food and Retail"*. For example, it was observed that SMEs had a lower implementation rate for environmental management system such as ISO 14001 compared to the MNCs. However, it was found from an interview with a Manager of a PCR Instrument Supplier that they have implemented ISO 14001 to reduce their carbon footprint from the funding scheme - 'Low Carbon Keep Project', supported by the European Regional Development Fund. Outcomes from the new product/processes developed from the influence of green strategies in both VC/SC and industrial actor level were observed to have structural influence (e.g. product characteristics, VC/SC process, capacity) targeted at certain parts of the value/supply chain. Due to the nature of waste generated through consumables used in the PCR and SMBG system, emphasis on the resource efficiency through eco design were observed. Similarly for the SMBG system, some companies are also looking into design for waste minimisation. For example, Roche has introduced a SMBG system that uses a cartridge system containing 50 tests, reducing the need to dispose each test strip. There are other companies looking into similar methods, and these activities can potentially have a structural influence on the product specific industrial system. Compared to the PCR and SMBG systems that have a relatively effective recycling system implemented due to regulatory compliance, product recovery for syringes and forceps are considered to be poor. Managing director of a Forceps Manufacturer has stated, *"Single use forceps are usually made from 401 stainless steel, which has fair second hand value that can be used for kitchen knives, but there is a massive gap in the UK market for recycling"*. The main reason for this was explained by a Clinical Waste Manager in a Waste Management Provider as, *"The challenge is within proper segregation at the source to stop material from getting into the waste stream since the containers are not allowed to be reopened after sealing, ending up with the material being sent for incineration"*. This leads to the importance of VC/SC level green waste management activity as an issue which can be resolved through partnering with a hospital to segregate, sterilise and send material to scrap for recycling. In the case of syringes, there is a high barrier to product recovery due to the significance of blood-borne diseases and the difficulty in recovering a product with multiple materials. One initiative observed was from Sharpsmart reducing waste through reusable sharps bins, which can create a 25% reduction in the volume of plastic in sharps waste. Both forceps and syringes green waste management activities can have a structural influence on the value chain, as well as a change in roles and relations between waste management providers and hospitals. There are various other structural influences regarding environmental sustainability at the VC/SC/actors level that are captured in figure 3.

Conclusion

The current UKMTS industrial system is not very proactive in terms of environmental sustainability in comparison to other industries such as automotive, food and retail. Analysis of the dynamics of environmental sustainability in the UKMTS industrial system illustrates that industrial actors require infrastructural influences from the existing external stakeholder to ultimately restructure the industrial system. As the UKMTS consists of 99% SMEs, this creates a significant challenge to implement environmental sustainability. It suggests there is a need that SMEs must be the central target of infrastructural influence by external stakeholders through research funding, regulation, collaboration etc. There is also specific difficulty in influencing the industrial actors through regulation in the UKMTS. There is a requirement for a more specific infrastructural influence for each product-based system from the external stakeholders, to effectively restructure the UKMTS. There are few MNCs collaborating with suppliers to identify opportunities across the value chain or hospitals and waste management companies collaborating toward increased product recovery and reduced carbon footprint This research positions contextual/business environmental elements of operation management into more dominant elements of an operational system. This was performed through a structure and infrastructure perspective on industrial systems frameworks, with specific emphasis on its dynamics/influences when approaching an industrial scale challenge. From the analysis of dynamics between environmental sustainability and industrial systems, it was found that external stakeholders make infrastructural decisions that enable industrial actors to influence the industrial system structure directly through a ‘carrot’ and ‘stick’ approach. Further research on the industrial systems of the UK Medical Technology Sector and other sectors are recommended for additional support of the data as well as to justify this new approach.

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